PERFORMANCE OPTIMIZATION OF DOMESTIC REFRIGERATOR USING EXPERIMENTAL METHOD

LAW CHEE HONG

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Faculty of Mechanical Engineering
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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature : ....
Name of Supervisor : MOHD YUSOF BIN TAIB
Position : LECTURER
Date : ....

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature : ……………………………

Name : LAW CHEE HONG

ID Number : MA06056

Date : ……………………………

Dedicated to my beloved parents

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ABSTRACT

This thesis deals with optimization performance testing for a domestic refrigerator using experimental method. As the refrigeration system has become one of the basic needs to us, the actual working principle is essential to be known by us so that we can always optimize the system performance and minimize the resources used. The objectives of this thesis is to improve a previous developed mini domestic refrigerator test rig by modifying the configuration of its tubing system, investigate the effect of refrigerant quantity on refrigeration system, and optimization performance of the mini domestic refrigerator test rig. The thesis describes the step by step fabrication of the tubing system of the mentioned test rig to achieve a simplest tubing system configuration for this refrigerator test rig. Vapor compression refrigeration system was studied as it is the most widely used refrigeration system especially in small scale of refrigeration application such as in domestic application. The design of the simpler tubing system will be depend on the location of other components in refrigeration system are located. The previous developed lengthy tubing system was greatly reduced in length by removing the thermocouple wires from the tubing system and moved it to the outer surface of the tubing. The improved refrigerator test rig was run and observed by using different quantity of refrigerant. The pressures and temperatures at the points of interest were observed and collected for all quantity of refrigerant. Finally, obtained the enthalpies for each of the points of interest and the optimum refrigeration coefficient of performance, COP_R, by using equations given. From the results, it is observed that the quantity of refrigerant does give significant effect on the performance of the refrigeration system. The obtained results indicate that there is a optimum point of refrigerant quantity for a particular refrigeration system depends on the capacity of the components in the system. The results concluded that the optimum performance achieved at the 35 psi initial charged refrigerant quantity which is at the lower refrigerant quantity out of the testing range of 35 to 45 psi initial refrigerant charged quantity. The results can contribute to understanding of the actual working principle of refrigeration system.

ABSTRAK

Tesis ini membentangkan kecekapan optimum bagi suatu peti sejuk domestik dengan menjalankan eksperimen. Oleh kerana sistem penyejukbekuan telah menjadi salah satu keperluan asas bagi kita, oleh itu prinsip berfungsi sebenar bagi sistem penyejukbekuan adalah penting untuk pengetahuan kita supaya kita dapat selalu mengoptimumkan kecekapan bagi suatu sistem penyejukbekuan dan meminimumkan kegunaan bahan mental. Objektif bagi tesis ini adalah untuk mempertingkatkan peti sejuk domestic kecil yang dibina sebelum ini dengan mengubah susunan sistem tiub-nya, mengkaji kesan kuantiti bahan penyejukan atas sistem penyejukbekuan, dan mengoptimumkan kecekapan peti sejuk kecil uji tersebut. Tesis ini menerangkan proses penghasilan sistem tiub yang baru dengan langkah demi langkah untuk mencapai susunan sistem tiub yang paling mudah bagi peti sejuk uji ini. Kemampatan wap sistem penyejukan dipelajari oleh sebab ianya adalah sistem yang paling banyak digunakan terutamanya di dalam sistem kecil seperti sistem bagi kegunaan domestik. Reka bentuk bagi susunan sistem tiub yang mudah adalah bergantung pada kedudukan komponen-komponen lain dalam sistem penyejukan tersebut. Sistem tiub yang panjang dibina sebelum ini telah banyak dikurangkan panjangnya dengan memindah termoganding yang sebelum dipasang di dalam sistem tiub ke permukaan tiub-tiub. Peti sejuk uji yang telah dipertingkatkan kualitinya dihidupkan dan diperhatikan dengan mengunakan kuantiti bahan penyejukan yang berbeza. Tekanan dan suhu di titik-titik yang berminat diperhatikan dan dicatat untuk semua kuantiti bahan penyejukan yang diuji. Akhirnya dapatkan enthalpi untuk setiap titik yang berminat dan koefisien kecekapan penyejukan optimum, COP_R, dengan mengunakan persamaan-persamaan dibagi. Dari keputusan, ia menunjukkan bahawa kuantiti bahan penyejukan dapat memberi kesan yang nyata atas kecekapan bagi suatu sistem penyejukbekuan. Keputusan yang diperolehi menunjukkan terdapat satu titik optimum kuantiti bahan penyejukan bagi sesuatu sistem penyejukbekuan yang tertentu dan ia bergantung pada kebolehan komponen-komponen dalam sistem tersebut. Keputusan diperolehi memutuskan kecekapan optimum tercapai pada 35 psi kuantiti awal isi bahan penyejukan yang mana ia ialah yang paling kurang di antara julat 35 psi dan 45 psi kuantiti awal isi bahan penyejukan yang diujikajikan dalam eksperimen ini.. Keputusan ini dapat menyumbang ke atas kefahaman dalam prinsip berfungsi sebenar dalam sistem penyejukbekuan.

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LIST OF SYMBOLS

COP	Coefficient of performance
COP_R	Refrigeration coefficient of performance
h	Enthalpy
$\dot{m}$	Mass flow rate
p	Pressure
Q_H	Heat rejection per unit mass
$\dot{Q}_H$	Heating capacity
Q_L	Refrigerating effect
$\dot{Q}_L$	Refrigeration capacity
s	Entropy
T	Temperature
T_H	High temperature
T_L	Low temperature
V	Voltage
W_c	Compressor work per unit mass
$\dot{W}_c$	Compressor work rate

LIST OF ABBREVIATIONS

CFCs	Chlorofluorocarbons
CFM	Coriolis flow meter
EMF	Electromotive force
EPA	Environmental Protection Agency
GWP	Global warming potential
HCFCs	Hydrochlorofluorocarbons
J	Thermocouple junction
MAPP	Methylacetylene-propadiene
R	Refrigerant
UMP	Universiti Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Refrigeration may be defined as the process to achieve and keep an enclosed space at a temperature lower than its surrounding temperature. This is done by continuous extraction of heat from the enclosed space whereas the temperature is below than that of the surrounding temperature.

Nowadays refrigeration is something that is indispensable in our daily life. One of the most important applications is the preservation of perishable foods and keeps the food in fresh condition. There is no doubt that food, is just like air and water are necessities for livings. People often utilize refrigeration to chill their drinks, making it more scrumptious. In additional, refrigeration also being used in providing thermal comfort to people by means of air conditioning process.

Historically, it is generally agreed that the first refrigeration machine was introduced in 1755 which was made by Scottish professor William Cullen. However, he did not use his discovery for any practical purpose. In the following 50 years, an American inventor, Oliver Evans, designed the first refrigeration machine. An American physician, John Gorrie, built a refrigerator based on Oliver Evans' design in 1844 to make ice to cool the air for his yellow fever patients. A German engineer named Carl von Linden patented not a refrigerator but the process of liquefying gas in 1876 that is part of basic refrigeration technology.

Generally refrigeration systems can be classified in 3 main cycle systems which are vapor compression refrigeration system, vapor absorption refrigeration system, and gas cycle refrigeration system. However the vapor compression refrigeration system is the most widely used in the refrigeration process. It is adequate for most refrigeration applications. The ordinary vapor compression refrigeration systems are simple, inexpensive, reliable and practically maintenance free.

However for large industrial applications, other refrigeration systems will be used to fulfill the effectiveness need. Jacob Perkins, an American living in London actually had designed the vapor compression refrigeration system and was built by Jacob Perkins in 1835 and had received his patent in 1834. The first practical vapor compression refrigeration system was made by James Harrison who took a patent in 1856 for vapor compression refrigeration system using ether, alcohol or ammonia as refrigerant.

Most of the domestic refrigerators today are running based on the vapor compression refrigeration system. It is somewhat analogous to a reverse Rankine cycle. The vapor compression refrigeration system contains four main components which are compressor, condenser, expansion device, and evaporator (Schmidt, 2006).

Compressor is used to compress the low pressure and low temperature of refrigerant from the evaporator to high pressure and high temperature. After the compression process the refrigerant is then discharge into condenser. In the condenser, the condensation process requires heat rejection to the surroundings. The refrigerant can be condensed at atmospheric temperature by increasing the refrigerant's pressure and temperature above the atmospheric temperature.

After the condensation process, the condensed refrigerant will flow into the expansion device, where the temperature of refrigerant will be dropped lower than the surrounding temperature caused by the reducing pressure inside the expansion device. When the pressure drops, the refrigerant vapor will expand. As the vapor expands, it draws the energy from its surroundings or the medium in contact with it and thus produces refrigeration effect to its surroundings. After this process, the refrigerant is ready to absorb heat from the space to be refrigerated. The heat absorption process is to be done in the evaporator. The heat absorption process is normally being called as evaporation process. The cycle is completed when the refrigerant returns to the suction line of the compressor after the evaporation process.

The performance of the domestic refrigerator is to be analyzed by using experimental method and attempt to improve and achieve the maximum performance for a unit of domestic refrigerator. In order to have more accurate results for analyzing the performance of the domestic refrigerator, the suitable locations of parameters to be recorded down to determine the performance of the domestic refrigerator is crucial to be identified. The experiment is carried out by using the previous developed test rig (mini size domestic refrigerator). The test rig is improved and modified if necessary.

Several different charge quantities of refrigerant will also be tested in the system and its effect on the performance of the refrigeration system is observed. This report is to give the basic understanding on vapor compression refrigeration system to the readers.

1.2 PROBLEM STATEMENT

As refrigeration has become one of the basic needs to modern people, it is important to know the actual working principle of the domestic refrigerator so that the users can always maintain the refrigeration system at its maximum performance. Therefore by understanding the working principle of the refrigeration system, it will allow the users to make the best use of the domestic refrigerator without wasting any electricity and materials used. There are 2 problem statements in this project, first is that study is needed to analyze the actual performance of refrigerator and second, is to determine the optimum COP_R by using different quantities of refrigerant charges on the improved previous developed refrigerator test rig.

1.3 OBJECTIVES

The main objective of this report is to improve the configuration of the refrigerator test rig to a simpler configuration. It is to avoid any significant pressure drop and heat transfer to and from the system throughout the refrigeration cycle and the effect of the charge quantity of the refrigerant on the refrigeration system. Finally, obtain the optimum COP_R by using the data collected from the experiment. To be able to do this, the exact locations of the points of interest at where the data (temperature and pressure) should be collected must be identified correctly.

1.4 SCOPES

1.4.1 Literature study

The literature study is mainly focused on the fundamental of working principle of vapor compression refrigeration cycle. The working principle of each of the 4 main components, compressor, condenser, expansion device and evaporator are also in the region of concerned. In this section, however, there is also a review of some techniques on how to fabricate the refrigeration tubing system.

1.4.2 Thermodynamics analysis

Clear understanding of vapor compression refrigeration cycle is needed so that the conditions of each critical state in the vapor compression refrigeration cycle can be easily determine and analyze. The temperature and pressure at the predetermined states or points in the cycle are the parameters of concern in the experiment of this project.

1.4.3 Improvement of experiment test rig

Set of experiments are conducted using previous developed refrigeration system test rig (mini size domestic refrigerator) in order to identify the best location where the parameters of concern will be recorded for the analysis of performance of the domestic refrigerator. Then the optimum COP_R of the test rig is obtained. Improvement and modification of the test rig should be done when it is necessary to get better results.

1.4.4 Testing and analysis

Analyze the data collected from the experiment by using pressure-enthalpy ($p - h$) diagram and determine the COP_R by using the second law of thermodynamics. The results are then discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 THE SECOND LAW OF THERMODYNAMICS

There are 2 classical statements of second law of thermodynamics which are the Kelvin-Planck statement and the Clausius statement. Both of Kelvin-Planck and Clausius statements are 2 equivalent expressions of the second law of thermodynamics. For refrigerators or heat pump, Clausius statement is being related to which is expressed as "It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower-temperature body to a higher temperature-body" (Cengel, 2008).

There is commonsense that heat does not naturally transfer on its own from a colder medium to a warmer medium. The Clausius statement simply means that if a cyclic device that transfers heat from a colder medium to a warmer medium will be impossible to be achieved or construct, unless this cyclic device produce a net effect on other (Cengel, 2008).

For an example, a cyclic device that transfers heat from a cold medium to a warmer one has long been constructed which is the domestic refrigerator. A domestic refrigerator is in complete compliance with the Clausius statement of the second law of thermodynamics. The Clausius statement simply states that a refrigerator can not operate unless its compressor is driven by an external power source, such as an electric motor. In this case, the compressor leaves a trace in the surroundings by consuming some energy in the form of work by the electric motor so that to transfer heat from the colder body to a warmer one (Cengel, 2008).

2.2 REFRIGERANTS

Over the last decade, the choice of refrigerant used in a refrigeration system has been becoming a worldwide issue as mainly in response to the environmental issues of "holes in the ozone layer" and "global warming or greenhouse effect".

Previously people had no much discussion on the selection of refrigerant. The refrigerants chosen were all based on the capability of heat absorption and releasing of the fluids, which depends on the latent heat of vaporization of the fluids. As the majority of applications could be met by the well known and well tested fluids, R-11, R-12, R-22, R-502 and ammonia (R-717). However only ammonia can be considered environmental friendly today, but still it is not readily suited to commercial or air-conditioning refrigeration applications because of its toxicity, flammability and attack by copper.

The ozone layer beyond the atmosphere provides a filter for ultraviolet radiation, which is harmful to us. The ozone depletion potential of the refrigerants such as R-11, R-12, R-114, and R502 is due to the emissions into the atmosphere of chlorofluorocarbons (CFCs). The Montreal Protocol in 1987 agreed that the production of hydrochlorofluorocarbons (HCFCs) would be phased out by 1995 with a consumption cap, followed by a 35 % reduction in consumption beginning in 2004 and alternative fluids developed (Trott, 2000). The phaseout of HCFCs is earlier in some European countries, with for example Germany having a phaseout of R-22 in new equipment starting in 2000, and Sweden banning HCFC use for new equipment after 1997, and service after 2001 (Murphy, 1998).

Global warming is the increasing of the world's temperatures, which results in melting of the polar ice caps and rising the sea levels. It is because the so-called "greenhouse" gases release into the atmosphere, which form a blanket and reflect heat back to the earth's surface, or hold heat in the atmosphere. The most infamous greenhouse gas is carbon dioxide (CO_2) (Trott, 2000).

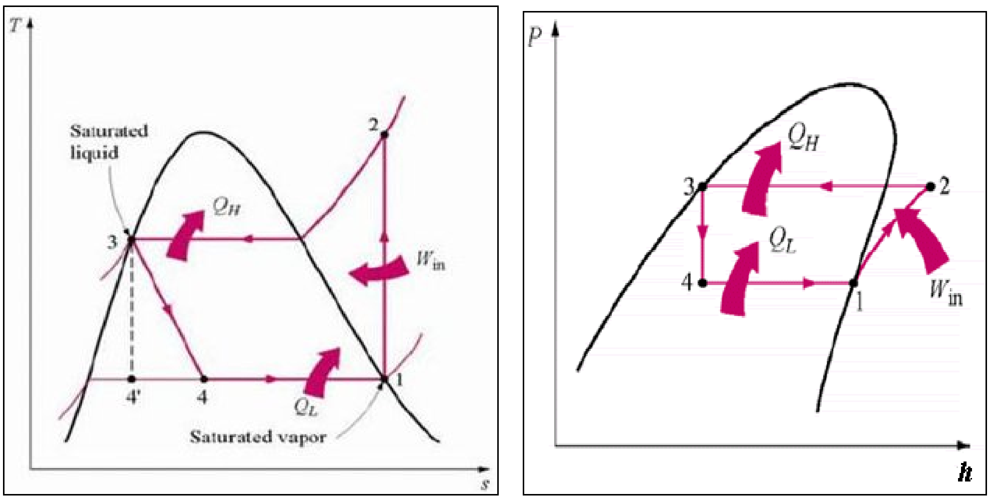
A newly developed refrigerant gas, R-134a is harmless to ozone layer. However, R-134a is not completely environmental friendly as it has a global warming potential (GWP) if released into the atmosphere. R-134a has a GWP of 1300, which means that the emission of 1 kg of R-134a is equivalent to 1300 kg of CO_2 (Trott, 2000).

In this experiment, R-134a will be used for the refrigerant. Therefore because of its GWP of 1300, additional care must take during the charging process and zero leakage must be ensured in the refrigeration system not only for the accuracy of the experimental results but also for the good for the environment.

2.3 VAPOR COMPRESSION REFRIGERATION SYSTEM

2.3.1 Ideal vapor compression refrigeration cycle

The Temperature-Entropy ($T-s$) and Pressure-Enthalpy ($p-h$) diagram for the ideal vapor compression refrigeration cycle are shown in Figure 2.1.



(a) (b)

Figure 2.1: (a) $T-s$ and (b) $p-h$ diagrams for the idea vapor compression refrigeration cycle

Source: Cengel and Boles (1998)

The vapor compression refrigeration system is the most common refrigeration system that is being used nowadays. It is widely used for all purpose refrigeration. It is commonly used for all industrial purposes from a small domestic refrigerator to big air conditioning plant. The vapor compression refrigeration system is an improved type of system of air refrigeration system. In this system, a particularly suitable working fluid is used to run the whole system and we called this working fluid as refrigerant. The refrigerant used is circulating throughout the system alternately condensing and evaporating without leaving the system (Khurmi, 2006).

It named vapor compression refrigeration system because the low pressure vapor refrigerant from the evaporator is being compressed into high pressure vapor refrigerant by the compressor in this system. There are 4 main components in vapor compression refrigeration system which is compressor, condenser, expansion device or capillary tube for the simple and small capacity units of refrigerators, and evaporator. The vapor compression refrigeration cycle consists of 4 processes.

For an ideal case, these 4 processes are isentropic compression by compressor, constant pressure heat rejection by condenser, throttling by expansion device and constant pressure heat absorption by evaporator (Khurmi, 2006).

In vapor compression refrigeration cycle, the cycle is said to be started when the refrigerant enters the compressor. In an ideal case, the refrigerant is in saturated vapor form when comes out from the evaporator. The saturated vapor refrigerant is then compressed isentropically by the compressor to high pressure and high temperature state where it reached state 2 as shown in Figure 2.1. At this state, the refrigerant is superheated and its temperature is well above the surrounding temperature which is usually the ambient temperature.

The refrigerant then enters the condenser at state 2 as superheated vapor. The superheated refrigerant vapor will be cooling down by the surrounding air that flows through and leaves the condenser coils as saturated liquid at state 3 as shown in Figure 2.1 (Cengel, 1998). As the superheated refrigerant changes phase from vapor to liquid phase, a large amount of heat will be released by the refrigerant at constant temperature